

Guidelines for Mix Design and Field Acceptance of

Cold In-Place Asphalt Recycling using Solventless Emulsion and Lime

965.01 Scope

This document provides methods and requirements for design, construction-management, and acceptance of cold-in-place recycled (CIR) asphalt pavement using solventless emulsion and lime slurry. It serves as a material design manual as well as guidance for UDOT personnel and consultants when managing a CIR project. These methods and requirements may also be used with centrally mixed recycled asphalt pavement using solventless emulsion and lime slurry

REFERENCES:

AASHTO Standards

- R 67 Sampling Asphalt Mixtures After Compaction (Obtaining Cores)
- T 2 Sampling of Aggregates
- T 27 Sieve Analysis of Fine and Coarse Aggregates
- T 84 Specific Gravity and Absorption of Fine Aggregates
- T 85 Specific Gravity and Absorption of Coarse Aggregates
- T 209 Theoretical Maximum Specific Gravity (G_{mm}) and Density of Hot-Mix Paving Mixtures
- T 245 Resistance to Plastic Flow of Asphalt Mixtures Using Marshall Apparatus
- T 248 Reducing Samples of Aggregates to Testing Size
- T 255 Total Evaporable Moisture Content of Aggregate by Drying
- T 283 Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture Induced Damage
- T 305 Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures
- T 312 Preparing and Determining the Density of Asphalt Mixtures Specimens by Means of the Superpave Gyrotory Compactor

Asphalt Institute SP 3

UDOT Materials Manual of Instruction (MOI)

UDOT Standard Specifications

UDOT Special Provisions

951.02 Definitions

CR	=	Coarse RAP material passing the 1 ½ inch sieve and retained on the No. 16 sieve.
FR	=	Fine RAP material passing the No. 16 sieve.
G _{CRb}	=	Bulk specific gravity of the coarse RAP material; loose or compacted as indicated
G _b	=	Specific gravity of the asphalt binder
G _{FRb}	=	Bulk specific gravity of the fine RAP material
G _{mm}	=	Maximum Theoretical Specific Gravity
h _{XX}	=	Height (mm) of specimen compacted at XX degrees F at 30 gyrations
Jc	=	The critical SCB fracture energy of a semi-circular specimen
M _b	=	Mass of the Emulsion Residue (g)
M _{CR}	=	Mass of the CR (g) (4000 g)
M _{Dry}	=	Mass of the RAP with lime in a specimen (g)
M _{FR}	=	Mass of the fine RAP in a specimen (g)
M _{MIX}	=	Mass of the total mix with emulsion residue but with no water (g)
M _{RAP}	=	Mass of the total RAP (g)
P _b	=	Asphalt binder content after distillation of emulsion as percentage M _{MIX} (percent residue of emulsion)
P _e	=	Emulsion content as a percentage of the M _{MIX} (initially estimate at 2.5 percent)
P _{FR}	=	Amount of fine RAP expressed as a percent of the M _{MIX} reported to 0.1 percent
P _L	=	Amount of lime as a fraction of the mass of the RAP. By specification 0.01 until adjusted by the TSR Test
RAP	=	Recycled Asphalt Pavement; material milled from the project location.
S	=	The slope of the compaction/temperature curve
T _{des}	=	The anticipated mat temperature during construction. Estimated by averaging the recorded high temperature from the nearest weather station from the previous five years and adjusting for mat temperature. See Appendix 8.
V _a	=	Volume of air voids (cm ³) in a specimen of mix compacted at T _{des}
%V _a	=	Air voids as a percent of the total volume of the mix (generally specified as 6 percent of the total volume of the mix)
V _b	=	Volume of asphalt binder (emulsion residue) (cm ³)
V _{CR80}	=	Volume of coarse RAP specimen compacted at 80 degrees F (cm ³)
V _{des}	=	Estimated volume of a specimen of mix compacted at T _{des} (cm ³)

V_{FR}	=	Volume of the fine RAP in a specimen (cm^3)
V_L	=	The volume of lime in a specimen (cm^3)
V_{XX}	=	Volume (cm^3) of specimen compacted at XX degrees F at 30 gyrations
VCR	=	Voids in a compacted coarse RAP specimen in cm^3 (The RAP equivalent of Voids in Coarse Aggregate (VCA))
%VCR	=	Voids in a compacted coarse RAP specimen expressed as a percent of total volume
VCR_{des}	=	Voids in the coarse RAP specimen compacted at design temperature (T_{des})
VCR_{xx}	=	Voids in a coarse RAP specimen compacted at XX temperature
%asphalt binder	=	Asphalt binder in the emulsion as a percentage of total emulsion (assumed 63 percent until provided by emulsion supplier)
% w_{FR}	=	percent water in the FR at liquefaction
% w_m	=	Amount of water in the mix at optimum as a percent of the total RAP in the mix

951.03 Selection Criteria

Proper selection of CIR projects is considered the most important factor in a successful project. Appendix 1 of this Manual contains Department guidelines for project selection.

951.04 Design Temperature

The design temperature is the anticipated temperature of the mat during construction. This temperature is used for mix designing.

1. Obtain the weather record from the Utah State Climate Center database

<https://climate.usurf.usu.edu/mapGUI/mapGUI.php>

2. Identify the closest weather station (within 500 ft. vertically) of the highest elevation on the project.
3. Determine the highest daily temperatures for a 7 day period in the middle of the expected construction days for last five years.
4. Average the highest daily temperatures and add 10 degrees F (T_{des}).

Note 1: The additional 10 degrees F is to offset for mat temperature above the ambient air temperature.

$$T_{des} = average + 10^{\circ}\text{F}$$

(Equation 1)

Unless the average of the highest daily temperatures + 10 degrees is less than 80 degrees F, then:

$$T_{des} = 80^{\circ}\text{F}$$

Or the average of the highest daily temperatures + 10 degrees is more than 120 degrees F, then:

$$T_{des} = 120^{\circ}\text{F}$$

Where:

T_{des} = the design temperature for the project
average = the average of highest daily temperatures for a 7 day period in the middle of the expected construction days for last five years.

951.05 Emulsion Qualification

Refer to project specifications.

951.06 Mix Design

951.06.01 Analyze RAP

1. The contractor obtains and submits a sample, 20 kg minimum, of the material from the pavement layer to be recycled. The sample must be representative of the CIR milling and crushing process.
 - a. The sample is obtained from the roadway after milling according to AASHTO T 2. If the sample cannot be obtained from milled material, sample from roadway according to AASHTO R 67, Obtaining Cores, and use a tabletop mill to represent the milling process.
2. Reduce sample for gradation. AASHTO T 248
3. Perform gradation using sieves listed in Table 1 (do not wash sample). AASHTO T 27

Table 1

Sieve Size
1 ½ inch
1 inch
¾ inch
½ inch
³ / ₈ inch
No. 4
No. 8
No. 16
No. 30
No. 50
No. 100
No. 200

4. From remaining sample, create Superpave Gyrotory Compacter (SGC) specimens of the *material passing the 1 ½ inch sieve and retained No. 16 material*, this will be referred to as the **CR (Coarse RAP)**.
 - a. Create two 4000 g samples of CR.
 - b. Compact one CR sample at 80 ± 2 degrees F and another CR sample at 120 ± 2 degrees F (AASHTO T 312, 30 gyrations); ensure the material is at testing temperature before placing in the gyratory mold.
 - c. Determine the height of the specimens at 30 gyrations from the SGC printout.

Note 2: It has been determined experimentally that RAP compacts to a smaller volume as temperatures rise between 80 and 120 degrees F. The relationship of rise in temperature to reduction in volume is linear. The slope of relationship is between 17 and 20 percent for all RAP sources. The slope of the relationship below 80 degrees F and above 120 degrees F has been shown to be relatively flat (little change in volume with temperature change). Testing on the coarse RAP has shown that this fraction behaves in the same manner as the total gradation. The slope and intercept of the temperature dependency curve is specific to each RAP source. This observation will be the basis to determine the mortar (fines + lime + emulsion) demand of the mix at any temperature.

Compacting to 30 gyrations has been determined to represent the compactive effort available in the field. This is the number of gyrations used for mix designing.

5. Calculate the *slope of the compaction / temperature curve* (S):

$$S = \frac{h_{120} - h_{80}}{120^{\circ}\text{F} - 80^{\circ}\text{F}}$$

(Equation 2)

Where:

S = the slope of the compaction/temperature curve

h_{80} = height (mm) of specimen compacted at 80°F

h_{120} = height (mm) of specimen compacted at 120°F

6. Calculate the *volume of the specimen compacted at 80 degrees F* (T_{80}):

$$V_{80} = \frac{\pi d^2 h_{80}}{4 \times 1000}$$

(Equation 3)

Where:

V_{80} = Volume of CR specimen compacted at 80 degrees F (cm^3)

d = Measured diameter of the specimen in mm (149.90 to 150.00 according to AASHTO T 312)

h_{80} = Height (mm) of specimen compacted at 80 degrees F (at 30 gyrations from SGC printout)

7. Calculate the *estimated specimen height at design temperature* (h_{des}).

$$h_{des} = h_{80} + (S \times (T_{des} - 80))$$

(Equation 4)

Where:

h_{des} = Estimated specimen height at T_{des} in mm

T_{des} = Design temperature

- a. Estimate the *volume of a specimen compacted at T_{des}* (V_{des}):

$$V_{des} = \frac{\pi d^2 h_{des}}{4 \times 1000}$$

(Equation 5)

Where:

V_{des} = Estimated volume of a specimen compacted at T_{des} (cm^3)

Note 3: The mix designing process will estimate the masses of the components of a theoretical specimen compacted at T_{des} using the estimated volume of a specimen compacted at T_{des} (V_{des}). Using the masses of the components of the theoretical specimen the percentages of each component is calculated for the final design.

8. Calculate the *estimated bulk specific gravity of the compacted CR* (Compacted G_{CRb}) of material at h_{80} and h_{des} .

- a. G_{CRb} of the Coarse Fraction compacted at T_{80} (Compacted G_{CRb} at 80)

$$\text{compacted } G_{CRb \text{ at } 80} = \frac{M_{CR}}{V_{80}}$$

(Equation 6)

Where:

Compacted G_{CRb} at 80 = Calculated bulk specific gravity of the CR at T_{80} (report to three places after the decimal)

M_{CR} = Sample mass (CR) (4000 g)

- b. Estimated *compacted G_{CRb} of the Coarse Fraction at T_{des}* (Compacted G_{CRb} at des)

$$\text{compacted } G_{CRb \text{ at } des} = \frac{M_{CR}}{V_{des}}$$

(Equation 7)

Where:

Compacted G_{CRb} at des = Calculated bulk specific gravity of CF at T_{des} (report to three places after the decimal)

9. Bulk Specific Gravity of the loose RAP:

Note 4: A RAP particle is considered a cemented aggregate particle for CIR (black rock). Although these particles change shape with temperature, their loose specific gravity remains constant.

- a. Coarse RAP (CR)
 - i. Determine the *loose CR Bulk Specific Gravity* (loose G_{CRb}). AASHTO T 85 (report to three decimal places).
- b. Fine RAP (FR) (material passing the No. 16 sieve)
 - i. Determine the *loose FR Bulk Specific Gravity* (G_{FRb}). AASHTO T 84 (report to three decimal places).
- c. Lime
 - i. The *specific gravity of Lime* (G_{Lb}) is between 2.4 and 2.5 (Lime Manufacturers Association). G_{Lb} may be estimated at 2.45 until G_{Lb} is provided by the supplier.
- d. Asphalt Binder (emulsion residue)
 - i. The *specific gravity of emulsion residue* (G_b) may be estimated at 1.020 until the G_b is provided by the supplier.

10. Determine the volume and percentage of the voids in the CR specimen after compaction at design temperature (VCR_{des}).

$$\%VCR_{des} = \frac{\text{loose } G_{CRb} - \text{compacted } G_{CRb \text{ at } des}}{\text{loose } G_{CRb}} \times 100$$

(Equation 8)

And:

$$VCR_{des} = V_{des} \times \%VCR_{des}$$

(Equation 9)

Where:

$\%VCR_{des}$ = Voids in the compacted CR expressed as a percent of the total volume

VCR_{des} = Volume of the voids in the compacted CR specimen (cm^3)

loose G_{CRb} = Bulk specific gravity of CR loose (AASHTO T 85)

compacted $G_{CRb \text{ at } des}$ = Calculated compacted Bulk Specific Gravity of the CR

V_{des} = Estimated volume of the specimen of mix compacted at T_{des} in cm^3

11. Calculate the *volume of air in a specimen compacted at T_{des}* (V_a).

$$V_a = \frac{\%V_a \times V_{des}}{100}$$

(Equation 10)

Where:

V_a = Volume of air voids (cm^3) in the specimen of mix compacted at T_{des}

$\%V_a$ = Specified air voids as a percent of the total mass of the mix (generally specified as 6 percent of the total mass of the mix)

12. Estimate the volume of the FR in the specimen.

Begin by estimating the *percent FR* (P_{FR}) and the *volume of the FR* (V_{FR}) in the specimen at 80 percent of the *voids in coarse RAP when it is compacted to T_{des}* (VCR_{des}). Then calculate the *mass of this estimated volume* (M_{FR}). When Step 17 is complete, this estimate will be refined to balance the volumes of the components (equation 21).

$$V_{FR} = P_{FR} \times VCR_{des}$$

(Equation 11)

Where:

V_{FR} = Volume of the FR (cm^3)

P_{FR} = Initial estimate of FR in an iterative process to fill the VCR_{des} (0.80)

VCR_{des} = Calculated voids in the CR specimen compacted at T_{des}

$$M_{FR} = V_{FR} \times G_{FRb}$$

(Equation 12)

Where:

M_{FR} = Mass of the FR

G_{FRb} = Bulk Specific Gravity of the FR (AASHTO T 84)

13. Calculate the *mass of the total RAP* (M_{RAP}) in a specimen based on the estimated M_{FR} and the known M_{CR} .

$$M_{RAP} = M_{CR} + M_{FR}$$

(Equation 13)

Where:

M_{RAP} = Mass of the total RAP (g)

M_{CR} = Mass of the CR (g) (4000 g)

M_{FR} = Mass of the FR (g)

14. Determine the *mass of the lime additive* (M_L) in the specimen. This is generally specified as 1 percent of the mass of the total RAP but may be increased based on the results of the Tinsel Stress Ratio (TSR) test. Begin with 1 percent. Then calculate the *estimated volume of this mass* (V_L).

$$M_L = P_L \times M_{RAP}$$

(Equation 14)

And:

$$V_L = \frac{M_L}{G_{Lb}}$$

(Equation 15)

Where:

V_L = Volume of lime

M_L = Mass of the lime (g). Initially $0.01 \times M_{RAP}$

P_L = Amount of lime as a fraction of the mass of the RAP. By specification 0.01 until adjusted by the TSR Test

G_{Lb} = Bulk Specific Gravity of Lime. Estimated at 2.25

15. Determine the *total mass of the dry portion of the mix* (M_{Dry}) in a specimen (RAP plus lime).

$$M_{Dry} = M_{RAP} + M_L$$

(Equation 16)

Where:

M_{Dry} = Total mass of RAP with lime in a specimen (g)

16. Determine the total mass of the combined mix in a specimen.

- a. Begin by assuming the *percent of asphalt binder content after distillation* (assumed P_b). The *estimated P_b* is determined later in the design process according to Asphalt Institute SP 3 and the optimum emulsion content (*optimum P_e*) by the Semi Circular Bending (SCB) test.

Note 5: The mix specimen will have two masses, one with emulsion and one with residue. The first is used to control the project and will be calculated later, the second is used in the volumetric design. The mass with emulsion residue is calculated in Equation 17. The emulsion must be 63 percent minimum asphalt binder as specified.

$$P_b = \frac{\% \text{asphalt binder} \times P_e}{100}$$

(Equation 17)

Where:

P_b = Asphalt binder content after distillation of emulsion as percentage of the mass of the mix (M_{MIX}) (percent residue of emulsion)

%asphalt binder = Asphalt binder in the emulsion as a percentage of total emulsion (assumed 63% until provided by emulsion supplier)

P_e = Emulsion content as a percentage of the M_{MIX} (initially estimate at 2.5%)

Example:

$$P_b = \frac{63\% \times 2.5\%}{100}$$

$$P_b = 1.6\%$$

Therefore the mass of the dry RAP plus lime is initially assumed to be 98.4 percent of the total mix (100.0 percent – 1.6 percent).

- b. Calculate the *estimated total mass of the mix* (M_{MIX}) in the specimen using the estimated percent residue.

$$M_{MIX} = \frac{M_{Dry}}{1 - \frac{P_b}{100}}$$

(Equation 18)

Where:

M_{MIX} = Mass of the total mix with emulsion residue in the specimen (g)

M_{Dry} = Mass of the RAP with lime in the specimen (g)

- c. Calculate the *mass and volume of the emulsion residue* (M_b and V_b) in a specimen.

$$M_b = \frac{P_b}{100} \times M_{Mix}$$

(Equation 19)

And:

$$V_b = \frac{M_b}{G_b}$$

(Equation 20)

M_b = Mass of the emulsion residue in the specimen (g)

V_b = Volume of the asphalt binder (emulsion residue) in the specimen (cm^3)

G_b = Specific gravity of the asphalt binder (residue)

17. Balance the volumes of the components in a specimen of mix compacted at T_{des} .

$$VCR_{des} - V_a = V_{FR} + V_L + V_b$$

(Equation 21)

Where:

VCR_{des} = Voids in the coarse RAP specimen compacted at design temperature (T_{des}) (cm^3)

V_a = Volume of air voids in the specimen (cm^3)

V_{FR} = Volume of fine RAP in the specimen (cm^3)

V_L = Volume of lime in the specimen (cm^3)

V_b = Volume of emulsion residue in the specimen (cm^3)

Re-run the equations beginning with a new estimate of the percent FR in the specimen; repeat with new estimates until the volumes in equation 21 balance within 0.1 cm^3 .

18. Determine the percentage of CR, FR, lime, and P_b and P_e based on the masses of the components in the theoretical specimen mass when equation 21 balances.

$$P_{CR \text{ Mix}} = \frac{M_{CR}}{M_{MIX}} \times 100$$

(Equation 22)

$$P_{FR \text{ Mix}} = \frac{M_{FR}}{M_{MIX}} \times 100$$

(Equation 23)

$$P_L = \frac{M_L}{M_{MIX}} \times 100$$

(Equation 24)

$$P_b = \frac{M_b}{M_{MIX}} \times 100$$

(Equation 25)

19. Determine optimum moisture ($\%w_m$). Appendix G.

20. Determine Maximum Theoretical Specific Gravity (G_{mm}), AASHTO T 209, of the following (report to three decimal places) using samples created using the percentages of the mix components determined in Step 18:

- a. The final RAP blend with lime ($G_{mm \text{ RAP}}$)
- b. The final RAP blend with lime and assumed P_e ($G_{mm \text{ MIX}}$).
 - i. Dry the final blend in air (less than 120 degrees F) until less than 0.1 percent mass loss after an additional 10 minutes of drying.

Note 6: The air-drying will assure the emulsion residue bonds to the RAP particles; reducing the chance of re-emulsification.

951.06.02 Determine Optimum Emulsion

1. Determine the *estimated* P_b according to Asphalt Institute SP 3.

Note 7: The estimated P_b is based on a 4.5 micron film thickness.

2. Using the estimated P_b perform steps 16 through 18 of 951.01 to revise the percentages of the mix components in the theoretical specimen mass.
3. Using the estimated P_b estimate the P_e .

$$P_e = \frac{P_b}{\%asphalt\ emulsion} \times 100$$

(Equation 26)

4. Using the estimated M_b estimate the M_e .

$$M_b = \left(1 + \frac{P_e}{100}\right) \times M_b$$

(Equation 27)

5. Revise the total sample mass using P_e in place of P_b ($M_{MIX\ e}$).
6. Using the $M_{MIX\ e}$ revise the percentages of each component in the theoretical specimen mass to create samples.
7. Determine the critical *SCB fracture energy* (J_c) of the mix according to Appendix B.
 - a. Prepare the test specimens:
 - i. At the estimated P_e , ± 0.5 percent
 - ii. Bring the mix to 77 ± 2 degrees F before placing in the gyratory mold
 - iii. Compact the specimen(s), AASHTO T 312 (30 gyrations)
 - iv. Cure the test specimen(s) for 72 ± 4 hours at 77 ± 2 degrees F (25 ± 1 degrees C)
 - b. Perform the SCB procedure at 77 ± 2 degrees F (25 ± 1 degrees C)
 - c. The target for J_c is -0.60
 - d. Adjust the P_e until the best fit line reaches $J_c = -0.60$

This emulsion content is the *optimum emulsion content* (optimum P_e).

951.06.03 Performance

1. Using the optimum P_e perform steps 2 through 6 of 951.06.02 to revise the masses of the mix components.
2. Determine draindown characteristics of the uncompacted mix at optimum P_e and Optimum Moisture using the revised percentages. AASHTO T 305. Draindown must be less than 0.2 percent of the total mix.
3. Determine *mass of mix at optimum moisture* ($M_{MIX\ opt}$).

$$M_{MIX\ opt} = (\%w_m \times M_{RAP}) + M_{MIX\ e}$$

(Equation 26)

Where:

$M_{MIX\ opt}$ = Mass of the total mix at optimum moisture

4. Using masses revised in Step 1 of this section and $M_{MIX\ wet}$ determine the percentages of mix components in the theoretical specimen mass at optimum moisture.
5. Create specimens at P_e and $\%w_m$ using the percentages revised in Step 4.
6. Determine the Marshall Stability of the mix at optimum P_e and $\%w_m$. AASHTO T 245
 - a. Prepare three samples of mix such that when compacted according to T 312 each 6 inch specimen is compacted to 80 ± 1 mm and percent air voids ($\%V_a$) is 94 ± 0.5 percent of G_{mm} .
 - b. Cure the mix for 24 ± 1 hours at 77 ± 2 degrees F (25 ± 1 degrees C)
 - c. Compact the specimen(s)
 - d. Perform the Marshall Stability Test procedure at 77 ± 2 degrees F (25 ± 1 degrees C)
7. Determine the Tensile Strength Ratio (TSR) of the mix at optimum P_e and $\%w_m$. AASHTO T 283
 - a. Bring the mix to 77 ± 2 degrees F before placing in the gyratory mold. Do not cure the material before compaction.
 - b. Compact the specimen(s). AASHTO T 312
 - c. Cure the test specimens for 72 hours ± 4 at 77 ± 2 degrees F (25 ± 1 degrees C)
 - d. Perform a single freeze thaw cycle

951.06.04 Determine Mix Design Proportions as a Percent of Total RAP

Values expressed as a percentage of the total mix are used for volumetric mix designing purposes. Values expressed as a percent of RAP are used for project control.

Determine component percentages as a percent of total RAP.

$$P_{CR\ RAP} = \frac{M_{CR}}{M_{RAP}} \times 100$$

(Equation 27)

$$P_{FR\ RAP} = \frac{M_{FR}}{M_{RAP}} \times 100$$

(Equation 28)

$$P_{L\ RAP} = \frac{M_L}{M_{RAP}} \times 100$$

(Equation 29)

$$P_{b\ RAP} = \frac{M_b}{M_{RAP}} \times 100$$

(Equation 30)

$$P_{e\ RAP} = \frac{P_b}{\%asphalt\ emulsion} \times 100$$

(Equation 31)

Example of theoretical specimen sample masses and percentages of the components expressed as a percentage of RAP and mix.

Mix Design	Weights (g)	% of RAP	% of Mix
Coarse RAP	4000	82.83%	76.06%
Fine RAP	829.4	17.17%	15.77%
Lime	48.3	1.00%	0.92%
Emulsion	123.9	2.57%	2.36%
Water	257.1	5.32%	4.89%
Total Weight	5258.7		

951.06.05 Mix Design Report

Provide a final report that lists the following mix design information:

1. Emulsion properties
 - a. Emulsion supplier
 - b. Emulsion designation
 - c. Emulsion residue content
 - d. Emulsion weight per gallon
 - e. G^* value of emulsion residue
 - f. "M" and "S" value of emulsion residue
2. Field table for calculating emulsion content based on field gradation and temperature.
3. RAP gradations
4. Percent Coarse RAP as a percent of dry RAP ($P_{CR\ RAP}$)
5. Percent Fine RAP as a percent of dry RAP ($P_{FR\ RAP}$)
6. Lime slurry target content as a percentage of dry RAP ($P_{L\ RAP}$)
7. Emulsion-Break Control-Moisture (optimum moisture) content target as a percentage of dry RAP ($\%w_m$)
8. Optimum emulsion content target as a percentage of dry RAP ($P_{e\ RAP}$) in the form of a target ± 0.2 percent, at Design Temperature.
9. VCR Target (VCR_{des}) based on the slope of the Temperature/VCR relationship curve
10. SCB Jc/emulsion content curve.
11. Marshall Stability at optimum P_e and $\%w_m$.
12. Retained Marshall Stability at optimum P_e and $\%w_m$.
13. Temperature sensitivity compaction curve as a % slope.

**951.07 Project Construction Management
Inspection, Sampling and Testing for Quality Control
Performed by the Department**

1. Station the project
 - Place a stake to the side of the project each 528 feet (10 divisions between mile markers) for location references.
2. Monitor Mat Temperature
 - Record the mat temperature and sunshine, i.e. sunny (S), partly cloudy (PC), and cloudy (C), at each test location on C 965-01. Sunshine is a significant factor in the mat temperature.
3. Monitor Gradation
 - Provide a mobile lab 5 minutes transit. Use wireless communication or other instantaneous means to transmit data.
 - Provide Results of control testing (Appendix F) to the processing equipment manager, through the Engineer's designated channels in less than 30 minutes after sample is obtained.
4. RAP Gradation Process Control

Gradation, moisture, and emulsion adjustments

 - Ensure the contractor obtains samples of the RAP and delivers to the lab within 5 minutes. AASHTO T 2, belt discharge.
 - Determine percentage of fines in the milled RAP (P_{FR}) and moisture content (M), Appendix F
 - Compare measured P_{FR} to the target
 - Cease production if measured P_{FR} is outside the action limit (02968S)
 - Adjust the moisture and emulsion contents, if necessary, when the P_{FR} is within the action limit.
 - Record all calculations and measurements on C 965-02.
5. Monitor Milling and Paving Operation
 - Monitor mill speed. Ensure the contractor obtains gradation tests as required.

- Verify the joint between the two recycled passes is clean and free of loose material.
 - Have areas where the processing machine leaks lime slurry or emulsion removed and replaced.
 - Verify the pickup machine is:
 - Picking up the windrow to within 1 inch of the milled surface.
 - Keeping up with the processing equipment.
 - Monitor the paver.
 - i. Is the mat segregating?
 - ii. Is it showing drag marks from the screed?
 - iii. Is the mat thickness correct?
 1. Observe the outer edge of the mat.
6. Monitor compaction, verify:
- The mat is reaching the design target temperature.
 - The mat is reaching the daily target temperature.
 - The knock down roller is getting on the mat as water begins to bleed from the pavement and off the mat when the surface begins to get tacky.
 - The pneumatic roller isn't causing the surface to bleed clear water.
 - The finish roller is holding off until the surface dries.
 - Density targets are being met.
 - The roller operator is paying attention to the longitudinal joints.
7. Monitor Release to Traffic
- Perform the DCP, Shear Vane and Marshall Field Hammer tests as required (Appendixes)
 - Release to traffic when targets are met.
8. Assure tack coat has been applied before covering the mat with asphalt paving.
9. Ensure the contractor provides an emulsion sample each day of processing.

Appendix A

Cold In-place Recycling (CIR) Project Selection Guidelines

Existing Pavement Structure – Evaluate the existing asphalt and base to determine its thickness and strength. The asphalt thickness under the proposed CIR must be at least 1.5 inch to support the CIR equipment during the process. The CIR pavement then must carry traffic during construction and until an overlay is placed.

Funding Availability - CIR can be constructed with a phased approach. CIR and a thin overlay can be placed during initial construction with additional overlays in the future.

Geometric Deficiencies - CIR can be used to correct minor variations in cross slope, but cannot be used to improve longitudinal or profile deficiencies. If there is sufficient pavement thickness, profile rotomilling can remove high spots or improve the crown of the road.

Road Elevation - Overhead clearance, curbs and gutters, drainage structures, shoulders, median barriers, and guardrails must be considered in the design. There is typically a fluff factor with CIR, adding a maximum 1/8 inch per 1 inch of CIR. Also, an overlay or preventive maintenance treatment is required on top of CIR further adding height. This may be mitigated by rotomilling the existing asphalt before CIR construction to adjust to desired elevation.

Traffic Control - Traffic control for CIR projects is similar to ‘mill and fill’ operations. Approximately 2.5 lane miles of CIR can be completed in one day. The CIR mat, requiring at least 2 hours of direct sunlight and fog sealing, can usually be opened to traffic within a few hours after processing. Placement should be complete early enough in the day to meet this requirement.

Project Selection

The following steps are recommended for CIR project evaluation:

Step 1 Conduct an In-Depth Pavement Distress Identification or Condition Survey

Use the *Distress Identification Manual for the Long-Term Pavement Performance Program* (LTTP) to determine the extent and severity of the pavement distress.

Step 2 Determine Whether the Cause of Pavement Distress Is Functional or Structural.

CIR can be used to fix functional distresses. CIR should not be used to fix pavements with structural deficiencies. Full Depth Reclamation (FDR) is an option for those projects. For projects that require more than a CIR, a combination of FDR and CIR can be used.

Determine whether pavement deterioration is functional or structural using the condition survey, coring, visual inspections, FDR, discussions with maintenance personnel, and any other resources available. Fatigue or alligator cracking located in the wheel paths, rutting, and patching can be indicative of structural inadequacy. Non-wheel path longitudinal cracking, block cracking, poor ride, flushing, or raveling can be considered functional distress. Proper field testing can be used to validate determinations.

After identifying the cause of distress, the method of rehabilitation can be determined. Ensure that corrective measures are taken to prevent similar problems in the future. Inadequate drainage is a common cause of pavement deterioration. If inadequate drainage is not addressed, the same problems will recur and premature pavement failure is to be expected.

CIR can treat the most common distresses, as shown in the following table. CIR may not be the correct treatment if there are inconsistencies in the existing asphalt pavement.

Pavement Conditions		
Distress	Criteria	CIR Applicability
Traffic	All Levels	Yes
Ruts	< 3/8 inch	Yes
	> 3/8 inch	Needs Further Considerations (a)
Crack	Fatigue	Needs Further Considerations (b)
	Longitudinal	Yes
	Transverse	Yes
Surface	Dry	Yes
	Flushing	Yes
	Bleeding	Yes
	Variable	Yes
Raveling		Yes
Potholes		Yes
Stripping		Needs Further Considerations (c)
Texture	Rough	Yes

Ride	Poor	Yes
Drainage	Poor	No (d)
Snow Plow Use		Yes
Low Skid Resistance		Yes
Other Criteria		
Rural		Yes
Urban		Needs Further Considerations (e)
Low Life Cycle Cost		Yes

- a) CIR is still applicable if the ruts have not been caused by base failure.
- b) Ensure that structural requirements can be met. CIR in conjunction with asphalt pavement overlay may be necessary.
- c) Determine severity and depth of existing layers that are affected. Consider an additive such as lime in the CIR to mitigate the issues. CIR mix design verification and overall structural enhancement will be critical.
- d) Improve poor drainage for adequate CIR performance.
- e) Geometrical constraints must be considered based on the type of recycling units used.

Step 3 Conduct Field-Testing to Validate and Quantify Field Condition Observations

After it is determined whether a pavement is experiencing functional or structural deficiency, conduct appropriate field testing to validate the assumptions for a successful CIR project.

Core the existing pavement to ensure adequate depth for the CIR process. Generally, the existing structural section must be at least the CIR depth plus 1.5 inch. For example, if a 3 inch CIR is required, then a minimum of 4.5 inch existing pavement is required. The intact structural section is required to accommodate the weight of the CIR train and prevent contamination of the CIR mixture with aggregate base during the CIR process.

The procedure and extent for obtaining cores or depth checks should be based on the condition survey identified in Step 1. If transverse cracking exists, obtain cores from the transverse crack to determine the depth of the existing surface and the crack. Cores should also be obtained at different locations longitudinally to assess the cross section of the roadway. Especially on low volume roads where the roadway may have been widened and inconsistent structural sections may exist.

See the following table for field testing and sampling guidelines.

Testing Scope	Sampling Frequency	Purpose
Pavement Layer Depths, Uniformity, Quality	Every ¼ mile	Determine feasibility and recycling depth; determine if additional mix designs are required for different sections of the roadway
Subgrade Soil	1 per mile, minimum	Determine structural design and support for equipment
FWD Survey (not completed on all projects) (a)	300 feet, maximum	Determine subgrade modulus and delineate soft spots
Bulk Pavement Sampling (b)	As needed to represent differing project conditions	Determine mixture quality and estimate application rates

(a) Other methods such as Dynamic Cone Penetrometer can be used

(b) Completed on projects with marginal conditions and if there is a concern about obtaining a quality product

Step 4 Laboratory Testing

Laboratory testing of the existing roadway is required to perform the required mix design. The designer is responsible for providing the mix design; the contractor provides cores or millings from the project.

Structural Section and Overlay Design: Department standards will be used to establish layer types and depths. A structural coefficient of 0.28 will be used for CIR according to the CIR special provision. Empirical or mechanistic-empirical methods, or both, can be used in the design of the structural sections. Typically a 2 to 4 inch CIR is used. Thickness should be at least two times the nominal size of crushed millings. Four inch is the maximum depth of CIR in one pass.

Step 5 Life-Cycle Cost Analysis (LCCA): A LCCA is recommended to determine the preferred alternative based on the lowest LCCA.

Step 6 Construction Practices: Proper construction and knowledgeable contractors are necessary for a successful CIR project. The department should obtain industry input and recommendations before the project is advertised. Effective communication, coordination, follow-ups on project performance, and documentation of lessons learned after completion of each project are key factors for building a successful CIR program.

Appendix B

Note B1: This method is used by permission of its author, Dr. Louay Mohammad at Louisiana State University.

This method references AASHTO T 67, a discontinued method of test. Please refer to ASTM E 4 for equivalent standard.

Method of Test for Evaluation of Asphalt Mixture Crack Propagation Using the Semi-Circular Bend Test (SCB)

1. SCOPE

- 1.1. This test method covers procedures for the preparation, testing, and measurement of fracture failure of semi-circular asphalt mixtures of specimens loaded monotonically.
- 1.2. This standard may involve hazardous material, operations, and equipment. This standard does not purport to address all safety problems associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1. AASHTO STANDARDS

- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 67, Load Verification of Testing Machines
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyrotory Compactor

3. SUMMARY OF TEST METHOD

Semi-Circular Bend Test UT T-1 EMCRF

- 3.1. A semi-circular specimen is loaded monotonically until fracture failure. The load and deformation are continuously recorded and the critical strain energy rate, J_c , is determined.

4. SIGNIFICANCE AND USE

- 4.1. The critical strain energy rate is used to compare the fracture properties of asphalt mixtures with different binder types.
- 4.2. This fundamental engineering property can be used as a performance indicator of fracture resistance based on fracture mechanics, the critical strain energy release rate, also known as J_c value.

5. APPARATUS

- 5.1. Load Test System- A load test system consisting of a testing machine, environmental chamber, and data acquisition system. The test system shall meet the minimum requirements specified below.
- 5.2. Testing Machine- The testing machine should be a closed loop system capable of applying a 4.5kN load monotonically under a constant cross-head deformation rate of 0.5 mm/min in a three point bend load configuration.
- 5.3. Environmental Chamber- A chamber for controlling the test specimen at the desired temperature is required. The environmental chamber shall be capable of controlling the temperature of the specimen at 25°C to an accuracy of +/- 1°C.
- 5.4. Measurement System- The system shall include a data acquisition system comprising analog to digital conversion and/or digital input for storage and analysis on a computer.

The system shall be capable of measuring and recording the time history of the applied load for the time duration required by this test method. The system shall be capable of measuring the load and resulting deformations with a resolution of 0.5 percent.

- 5.4.1. Load- The load shall be measured with an electronic load cell having adequate capacity for the anticipated load requirements. The load cell shall be calibrated in accordance with AASHTO T 67.
- 5.4.2. Axial Deformations- Axial deformations shall be measured with linear variable differential transformers (LVDT).

- 5.4.3. Temperature- Temperature shall be measured with Resistance Temperature Detectors (RTD) accurate to within +/- 1°C
- 5.5. Gyratory Compactor- A gyratory compactor and associated equipment for preparing laboratory specimens in accordance with AASHTO T 312 shall be used.
- 5.6. Saw- The saw shall be capable of producing three different notch sizes ranging from 0 – 50 mm. The width of the saw blade shall be 3.0mm.
- 5.7. Loading Frame- The loading frame shall consist of a loading rod and two sample support rods. The schematic of the test apparatus is shown in Figure x (need permission from ATM). The diameters of the loading and supports rods shall be 25.4 mm and the anvil span shall be 127.0 mm.

6. TEST SPECIMENS

- 6.1. Semi- circular bend testing may be performed on field cores or laboratory prepared test specimens.
- 6.2. Specimen Size- The test specimen shall be 150 mm diameter and 57 mm thick.
- 6.2.1. The semi-circular shaped specimens are prepared by slicing the 150 mm by 57 mm specimen along its central axis into two equal semi-circular samples.
- 6.2.2. Field cores can also be used if pavement is at least 57 mm.
- 6.3. Notching- A vertical notch is introduced along the symmetrical axis of each semicircular specimen. The three nominal notch sizes are 25.4 mm, 31.8 mm, and 38.1 mm. The notch depth tolerance is ± 1.0 mm. The width of the notch shall be 3.0 ± 0.5 mm
- 6.4. Prepare four test specimens at the target air void content $\pm 0.5\%$.
- 6.5. Aging- Laboratory-prepared mixtures shall be temperature-conditioned in accordance with the oven conditioning procedure outlined in AASHTO PP2. Field mixtures need not be aged prior to testing.
- 6.6. Air Void Content- Prepare four test specimens at the target air void content $\pm 0.5\%$.
- 6.7. Replicates- Four specimen should be tested at each at each notch depth (25.4-, 31.8-, and 38.1-mm).

7. PROCEDURE

- 7.1. Place the specimen on the bottom support, ensuring the support is centered and level (as shown in Figure 1), in the environmental chamber and allow it to stabilize to 25°C. A

dummy specimen with a temperature sensor mounted to its center can be monitored to determine when the specimen reaches 25°C. In the absence of a dummy specimen, a minimum of 0.5 hours from room temperature is the required temperature equilibrium time.

- 7.2. After temperature equilibrium is reached, apply a preload of 10 lb to specimen to ensure the sample is seated properly. After ensuring the sample is level, release the load.
- 7.3. Begin to apply load to specimen in displacement control at a rate of 0.5 mm/min ensuring that time, force, and displacement are being collected and recorded. During the test have the load versus displacement plot visible, paying close attention to the peak load. Test may be terminated 120 seconds after peak load is reached.

8. CALCULATIONS

$$J_c = - \left(\frac{1}{b} \right) \frac{dU}{da}$$

where:

b = sample thickness

a = notch depth

U = strain energy to failure.

- 8.1.1. Strain energy to failure, U is the area under the loading portion of the load vs. deflection curves, up to the maximum load measured for each notch depth (shown in Figure 2).
- 8.2. The specimens are randomly clustered into 4 groups of three (one specimen at each notch depth within the grouping) before testing. Each cluster of three notch depths may be analyzed individually. The three values of U (one at each notch depth) are plotted versus their respective notch depths. The data is then modeled with a linear regression line (shown in Figure 3). The slope of the linear regression line represents the strain energy release rate.
- 8.3. The critical value of J-integral (J_c) then computed by dividing the slope of the linear regression line (dU/da) by the specimen thickness, b.

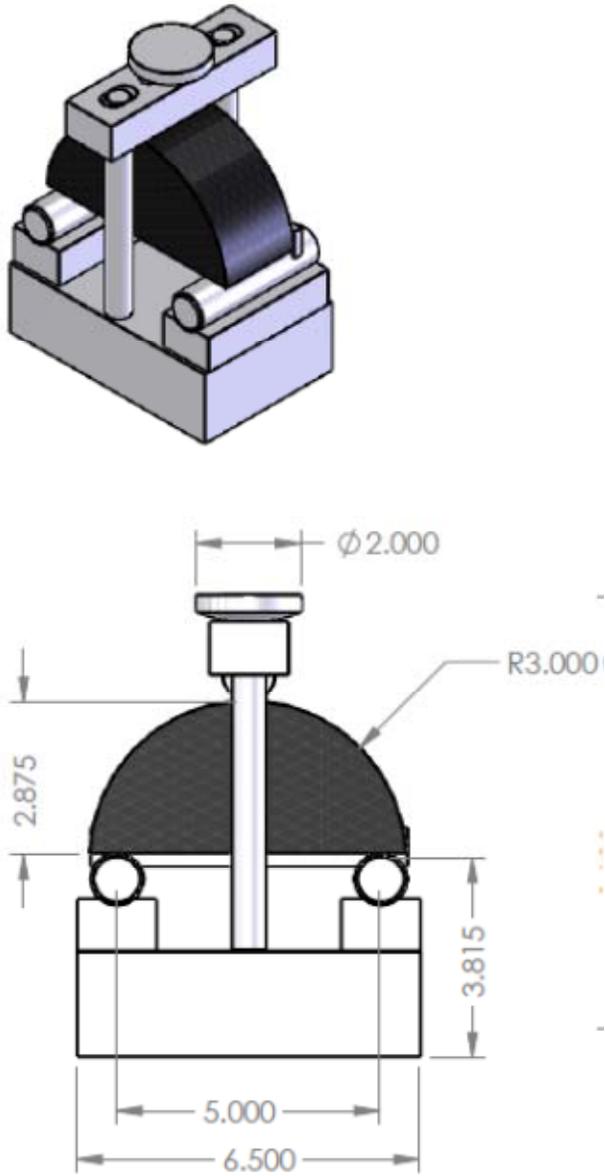


Figure 1: Schematic of the loading apparatus



Figure 1: Loading Position

Figure 2:

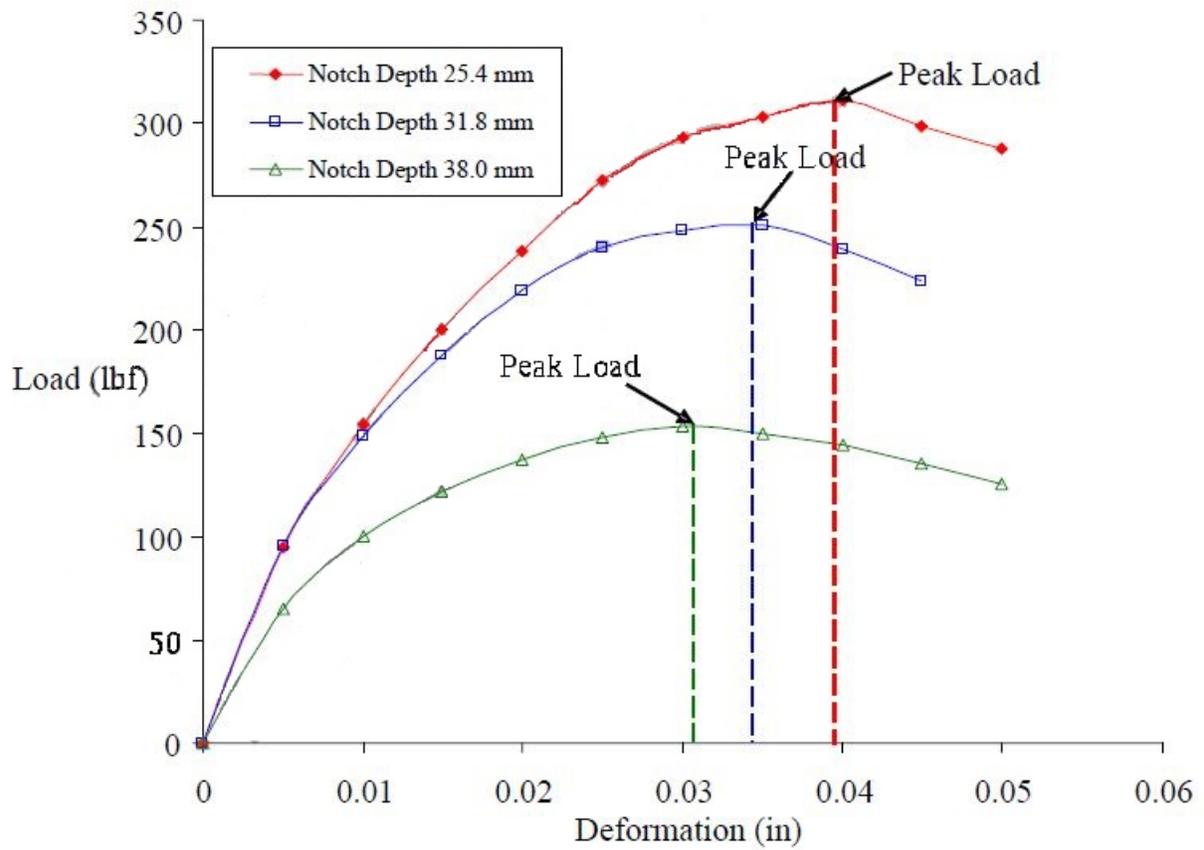


Figure 2: Deformation versus Load

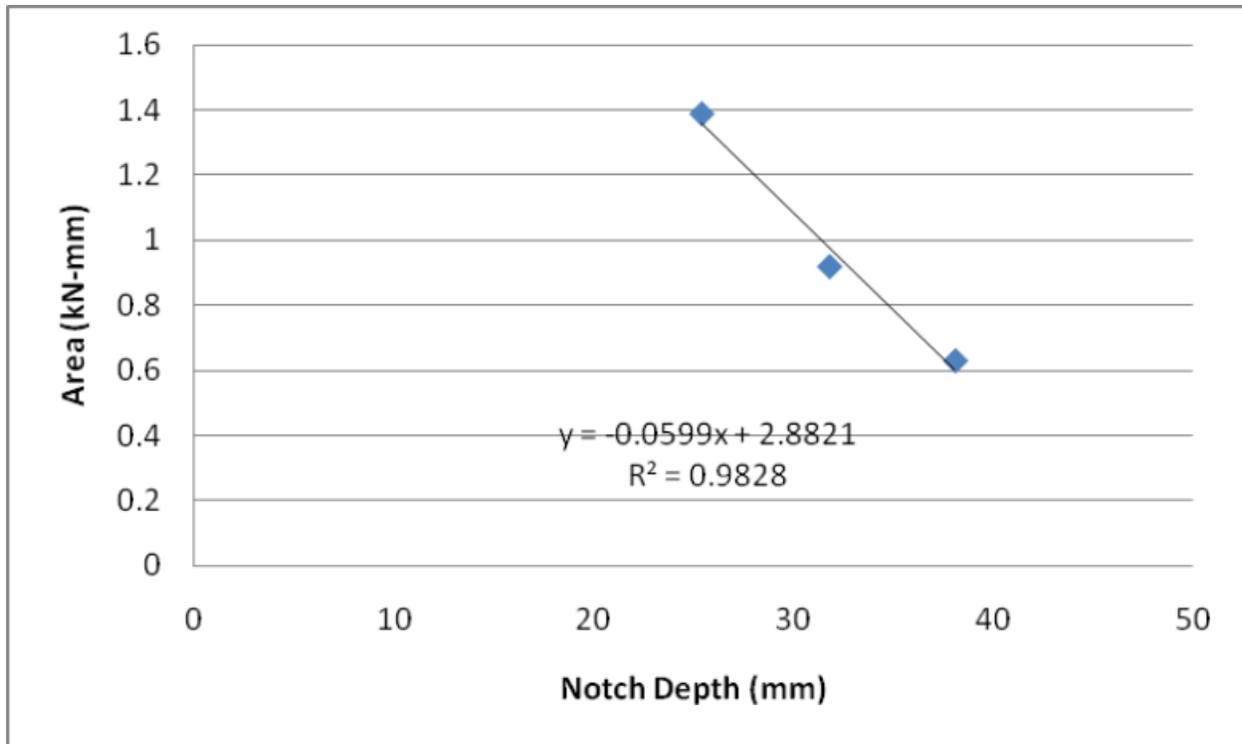


Figure 3: Notch Depth versus Area

9. REPORT

9.1. *The report shall include the following parameters:*

9.1.1 Asphalt Mixture Type;

9.1.2 Test Temperature, °C;

9.1.3 Specimen Air Voids, %;

9.1.4 J_c per Notch Depth, kJ/m²;

9.1.5 Coefficient of Determination, R_2 ;

9.1.6 Mean J_c Value, kJ/m²;

9.1.7 Standard Deviation of J_c ;

9.1.8 Coefficient of Variation, %.

Appendix C

Cold In-Place Recycled Asphalt Dynamic Cone Penetrometer (DCP) Test

XC.01 Scope

This test method is for performing Dynamic Cone Penetrometer (DCP) testing on Cold In-Place Recycled (CIR) asphalt pavement to determine the progression of curing after compaction.

REFERENCES:

ASTM D 6951, Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications

XC.02 Apparatus

- Dynamic Cone Penetrometer (DCP) with 17.6 lb. weight (17 lb. nominal) and 1 inch diameter tip (DCP assembly). ASTM D 6951.
- Measuring device (e. g. ruler) capable of measuring in millimeters.

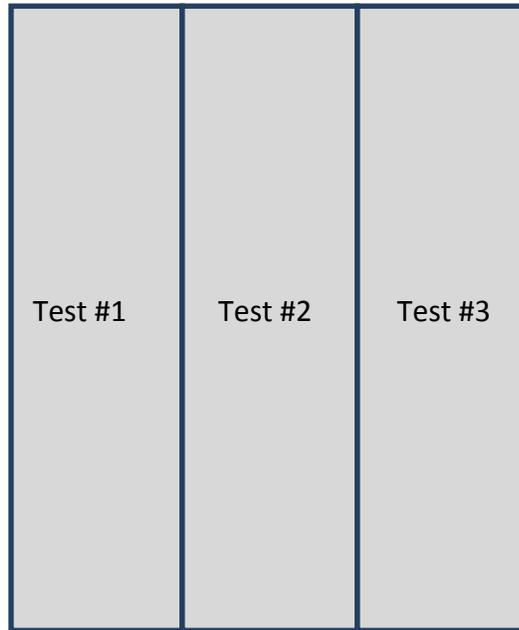


XC.03 Procedure

1. Select a test location according to project specifications; at least 1 ft. from other test sites.
2. Divide the test location in three segments longitudinally across the paver pass and at least 1 ft. from the edge. Perform the test procedure in each segment.
3. Zero the measurement

- a. Assemble the DCP with the 17 lb. hammer section, the spacing rod and the 1 inch diameter tip.
 - b. Determine a surface on the hammer head to be used as a measuring reference, usually the upper surface of the hammer due to the ease of reading the ruler using this reference.
 - c. Place the ruler and the DCP assembly side by side vertically on a hard level surface so that they are parallel (concrete curb, sidewalk, paved road, etc.). Place the hammer on the bottom stop.
 - d. Measure and record the height of the DCP reference surface.
 - e. Use this number as the initial set number. This measurement will represent the height of the hammer with an unseated cone. The difference between this measurement and the measurement taken when the cone contacts the milled surface at the bottom of the recycled mat indicates the depth of CIR at each test location.
4. Hold the DCP assembly perpendicular to the mat with the cone touching the mat at the test location.
 5. Drop the weight and record the penetration in mm.
 6. Repeat Steps 4 and 5, record the number of drops (blows) and depth, until the DCP does not penetrate further or has exceeded the depth of the CIR asphalt.

Note C1: Occasionally the mat is very dense and penetration per blow is small. In this case the number of blows used between recording the depth may be increased. A reasonable standard is to record the number of blows required to penetrate 10 mm.
 7. Remove the DCP assembly, repair the CIR mat by pressing loose material into the hole and coating the site with emulsion.
 8. Repeat test procedure in each segment.



CIR placement pass divided into three segments. Perform one test in each segment at each location. Location result is the average of the test results of all three segments.

9. Divide maximum depth by number of blows (mm/blows) to determine penetration per blow in each segment.
10. Average the penetration per blow results from each segment and record.

XC.04 Report the following for each location on Form 965-03:

- Time and date of the test
- Location and segment (offset) of the test
- Total depth of the test (mm)
- Number of blows required to reach the total depth
- Penetration per blow (mm/blow) for each segment
- Average penetration per blow (mm/blow)

Appendix D

Cold In-Place Recycled Asphalt Field Shear Vane Test

XD.01 Scope

This procedure provides a method for performing Shear Vane testing on Cold In-Place Recycled (CIR) asphalt to determine the progress of curing after compaction.

XD.02 Apparatus

- Sledge hammer, 5 lb minimum
- Torque wrench capable of reading to 150 ft/lb
- Shear vane (Figure 1)
- 15/16 inch socket



Photo of Shear Vane with socket attached

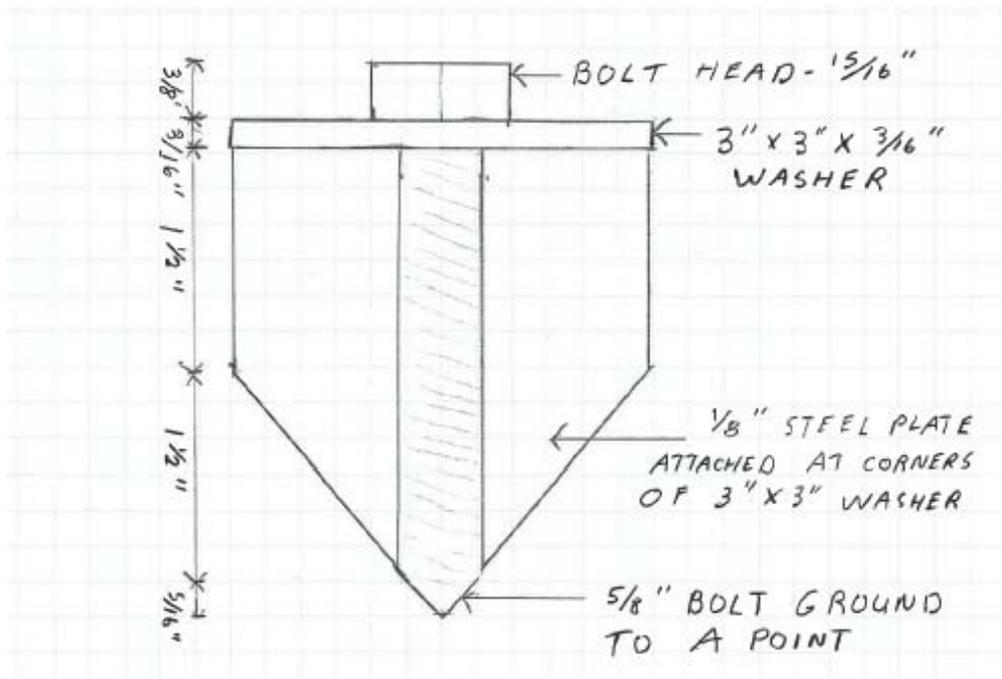


Figure 1 - Shear Vane dimensions

The Shear Vane is constructed by welding 1/8 inch steel plates to a 5/8 inch bolt and a 3/16 inch washer from the edges of the washer to the center.

XD.03 Procedure

1. Select a test location according to project specifications and at least 1 ft. from the edge of the CIR pass and other test sites.
2. Using the hammer, drive the Shear Vane into the CIR, keeping the Shear Vane vertical, until the washer sits flush on the surface.

Note D1: The socket must be on the bolt head before striking with the hammer so that the Shear Vane is not damaged. Care must be taken to keep the device as vertical as possible to minimize damage to the CIR before testing.

3. Place the torque wrench onto the head of the Shear Vane bolt. Apply slight downward pressure to ensure that the Shear Vane does not lift during the test.
4. Evenly apply pressure to the torque wrench (90 degrees in 10 seconds) while watching the dial closely. Apply increasing pressure until the CIR material is broken loose by the Shear Vane.

5. Record the highest torque value reached during test.
6. Determine and record pavement temperature at 2 inches below surface.
7. The test will leave a hole in the mat, repair by pressing loose material into the hole and coating the site with emulsion.

XD.04 Record the following on Form 965-03:

- Time and date of the test
- Location
- Maximum torque value achieved in ft/lbs
- Pavement temperature at a depth of 2 inches

Appendix E

Determining In-place Flow of Cold In-place Recycled (CIR) Asphalt using the Marshall Hammer

Use this procedure for quick evaluation of flow characteristics of CIR mat to determine appropriate hold time for CIR mixes before finish compactive efforts and release to traffic.

XE.01 Apparatus

- *Marshall Hammer: A Manual or automatic hammer as described in AASHTO R 68, Preparation of Asphalt Mixtures by Means of the Marshall Apparatus.*

XE.02 Field Procedure

1. Perform test on the initially compacted mat.
2. Place the Marshall hammer with its head flat on the mat. Do not move the hammer or rock the head.
3. Pick up the sliding weight until it reaches the upper stop. Drop the weight. Repeat 50 times.
4. All measurements are from the level of the undisturbed mat.
 - a. Measure the depth of the depression made by the hammer in mm.
 - b. Measure the height of the lateral deformation, if any, in mm.
5. Determine the moisture condition of the mat. (Water bleeding from the mat or is it dry?)
6. Determine temperature of the mat to the nearest 1 degree F.

XE.03 Report on Form 965-03

- Test location
- Mat temperature
- Depth of depression, mm
- Height of lateral deformation (Ht LD), if any, mm
- Moisture condition

XE.04 Determination of CIR Sample Cure Time

The mat is not ready for final rolling if the depression is greater than 10 mm, the height of the lateral deformation is greater than 5 mm or if the mat is bleeding.

Appendix F

Standard Method to Rapidly Obtain the Percentage of Fines in RAP Millings

Use this method to rapidly determine the dry ratio of RAP mass above (Coarse RAP (CR)) and below (Fine RAP (FR)) the No. 16 sieve. These results are used to determine and control the percent mastic in the CIR mix.

All testing equipment and supplies are required to be within 5 minutes of the CIR processing unit so that results may be provided to the processor operator within 30 minutes.

XF.01 Sample

1. Have the contractor obtain a sample of milled RAP from below the scalping sieve but above the pugmill on the recycling train. The sample must be:
 - a. A complete cross section of the flow from the mill and from the crusher. If the flow separates into two streams, sample each flow for an equal time.
 - b. 10 kg minimum
2. Reduce the sample using a riffle splitter. AASHTO T 248
3. Obtain a 1.2 kg sample for testing.
4. Determine and record wet mass (W) of the sample to the nearest 0.1 g.
5. Spread the sample out on a surface so that the large particles are not stacked.
6. Dry the sample at 110 degrees F or less until particles separate easily in an air stream moving 5 ft. per second or less.
7. Separate the sample into CR and FR portions by shaking a nest of sieves containing the $\frac{3}{4}$ inch, No. 4, No. 8 (to minimize overloading), and No. 16 sieves. AASHTO T 27.
8. Brush the larger particles on each sieve with a soft bristle brush to remove the small particles and pass them through the sieve.
9. Determine dry mass of the CR:
 - a. Recombine the material retained above the No. 16 sieve (CR).
 - b. Dry in a microwave oven according to AASHTO T 255 until there is less than 0.5 percent mass loss in an additional 2 min. of drying.

c. Cool and record dry mass of the CR (D_{CR}) to the nearest 0.1 g.

10. Determine the dry mass of the FR:

a. Dry in a microwave oven according to AASHTO T 255 until there is less than 0.5 percent mass loss in an additional 2 min. of drying.

b. Cool and record dry mass of the FR (D_{FR}) to the nearest 0.1 g .

XF.02 Calculations

$$D = D_{CR} + D_{FR}$$

(Equation X6.1)

Where:

D = total dry mass of sample

D_{CR} = dry mass of coarse RAP (CR)

D_{FR} = dry mass of fine RAP (FR)

$$P_{FR} = \frac{D_{FR}}{D} \times 100$$

(Equation X6.2)

Where:

P_{FR} = portion of fine RAP expressed as a percent of the total dry sample reported to 0.1 percent

$$M = \frac{W - D}{D} \times 100$$

(Equation X6.3)

Where:

M = total moisture content of RAP sample expressed and percent of dry sample mass reported to 0.1 percent

XF.03 Report the following on Form 965-02:

Return results to the Engineer's designated representative within 30 minutes after the sample is obtained.

- Wet mass of the sample (W)
- Dry mass of the CR (D_{CR})
- Dry mass of the FR (D_{FR})
- Total dry mass of sample (D)
- Percent of the FR in the total sample (P_{FR}) to 0.1%
- Moisture content of the whole sample (M) to 0.1%

Appendix G

Determining Optimum Moisture of a CIR Mix

This procedure is used to determine the moisture content required in the mix to prevent emulsion break by determining moisture content of fine RAP (FR) at point of liquefaction. Liquefaction is a condition of the FR where moisture is driven to the surface by vibration. It is characterized by the surface developing a sheen and a smooth, shiny texture. Lime slurry moisture content should be included in this moisture content.

1. Prepare a 100 g sample of fine RAP with the following gradation.

Sieve Size	% Passing
No. 16	100
No. 30	50
No. 50	25
No. 100	13
No. 200	5

2. Add 5 g of lime (Lime content is assumed at 1 percent of the mass of the RAP and that 20 percent of the RAP is FR)
3. Add 25.2 g water (24 percent of the RAP and lime)
4. Vibrate the sample at 50 Hz for 15 seconds. A VIBCO SCR-50 bin vibrator mounted on a table is an acceptable apparatus.
5. Observe the surface of the sample for the appearance of liquefaction.
6. Add water in 2.1 g (2 percent of RAP and lime) increments and repeat vibration and observation.
7. Repeat Steps 4 through 6 until liquefaction is achieved. Record total amount of water added.

8. Determine *water content percentage at liquefaction* ($\%w_{FR}$):

$$\%w_{FR} = \frac{\text{water}}{FR + L} \times 100$$

(Equation XG.1)

Where:

$\%w_{FR}$ = percent water in the FR at liquefaction

FR = fine RAP sample mass (100 g)

L = lime (5 g)

This is the required moisture content to prevent emulsion break.

Calculate the optimum moisture content of the total mix ($\%w_m$) based on the *percent FR in the mix* (P_{FR}) and the percent water in the FR at point of liquefaction.

$$P_{FR} = \frac{\frac{V_{FR}}{G_{FRb}}}{\frac{V_{des}}{G_{mm-RAP}}} \times 100$$

(Equation XG.2)

Where:

P_{FR} = amount of fine RAP expressed as a percentage of total RAP

V_{FR} = Volume of fine fraction of the RAP in a specimen (cm^3)

V_{des} = Estimated volume of specimen compacted at T_{des} (cm^3)

And

$$\%w_m = \frac{\%w_{FR}}{P_{FR}}$$

(Equation XG.3)

Where:

$\%w_m$ = Amount of water in the mix at optimum as a percent of RAP

$\%w_{FR}$ = percent water in the CF at liquefaction

Report:

Percent water in the fines at liquefaction ($\%w_{FR}$)

Percent water in the mix at optimum ($\%w_m$)

Appendix H

Example Mix Design Spreadsheet

Cold Asphalt Recycling Mix Design Procedure

Step		Assume	Measure	Calculate		Weight (g)	Mix Weight (g)	Volume (cm ³)	Mix Volume (cm ³)
4a	Coarse RAP Weight (g)	4000				4000			
9a	Coarse RAP Gravity		2.223						
	Coarse RAP Min Volume (cm ³)			1799.4				1799.4	
	Coarse RAP Compacted Volume (cm ³)							2691.4	
8b	Calculated specific gravity C _{ca}			2.223					
	VCR compacted % at Tdes		24.07%						
10	Volume of Fine RAP % of VCR	66.40%							
Use this to balance	Volume of Fine RAP (cm ³)			378.7				378.7	
9b	Fine RAP Gravity		2.190						
12	Mass of Fine RAP (g)			829.4		829.4			
8a	Calculated specific gravity F _a			2.190					
11	Volume of Air in C _{ca,des} (cm ³)			1573.5					
13				Total RAP Weight-Volume			4829.4		2178.1
14	Lime % of dry RAP	1.00%							
	Lime Weight (g)			48.3		48.3			
9c	Lime Gravity		3.330						
	Lime Volume							14.5	
15				Total RAP + Lime Weight-Volume			4877.7		2192.6
16a	Emulsion % of total mix	2.50%							
	Mass of emulsion (g)			123.9					
	Asphalt content of Emulsion	63.00%		1.58%					
16b	Asphalt Residue % of mix								
	Mass of the mix (g)			4955.8					
	Mass of the asphalt residue (g)			78.1		78.1			
9d	Specific gravity of the asphalt residue	1.024							
	Volume of the asphalt Residue (cm ³)			35.0				35.0	
				Total RAP + Lime + asphalt residual Weight-Volume			4955.8		2227.6
21	Specific Gravity of the mix		2.227	2.225				Match	
17	Use the % volume of the fine RAP to balance the equations					Volume of the Mix	2227.6	2227.6	VCR minus 6% Air
	Target Air %	6.00%							These must match within 0.1 cm ³
19	Optimum Water Content Worksteet								
	Mass of Fine RAP			829.4					
	% water to liquefaction of Fine RAP		31.00%						
	Weight of water to liquefaction (g)			257.1					
20	Build a wet sample								
18	Mix Design	Weights (g)	% of RAP	% of Mix					
	Coarse RAP	4000	82.83%	76.06%					
	Fine RAP	829.4	17.17%	15.77%					
	Lime	48.3	1.00%	0.92%					
	Emulsion	123.9	2.57%	2.36%					
	Water	257.1	5.32%	4.89%					
	Total Weight	5258.7							
	You can now scale this to any sample size								

Worksheet for Coarse RAP Compacted Volume Step 4

Measured Height at 80°F, 30 gyrations (cm)	15.23
Diameter of Puck (cm)	15
Step 6 Volume at 30 gyrations at 80°F	2691
VCR % at 80°F	33.14%
Step 5 Slope of Temperature sensitivity	18.20%
951.04 Design Temperature (F)	90
Step 7 Calculated hight at Tdes	13.41
Step 8 Volume at 30 gyrations at Tdes	2369.7
VCR % at Tdes	24.07%
The height of the puck is proportional to the weight of	

the sample
 If the weight of the sample is increased by one third, the height is increased by one third.
 Once the VCR at 80 °F and 30 gyrations is known, it doesn't matter what the sample weighs, the VCR % at 80 degrees remains the same. This allows the sample to be scaled around the VCR%

Appendix I

Construction Forms

C 965-02 Gradation and Moisture Content

Rev 1/16									C 965-04		
CIR DENSITY DAILY REPORT											
								PAGE	1	of	1
PROJECT					PR			DATE			
CIR CONTRACTOR							DAY OF WEEK				
PAVING CONTRACTOR											
WEATHER							GAUGE S.N.				
CIR EMULSION							STD. COUNT M				
CONTRACTOR'S EQUIPMENT							STD. COUNT D				
TECHNICIAN NAME							TTQP QUAL. NUMBER				
TEMPERATURE TARGET/ DAY				ACTUAL TEMPERATURE / DAY							
TEST #	LOCATION	LIFT	SAMPLE #	THEORETICAL MAX. DENSITY	FIELD DENSITY (rotate 180°)	AVG. FIELD DENSITY (pcf)	PERCENT COMPACT.	TARGET			
1								94%			
2								94%			
3								94%			
4								94%			
5								94%			
6								94%			
7								94%			
8								94%			
9								94%			
10								94%			
TIME BEGIN			TIME FINISH			HOURS			MILEAGE		
REMARKS / LOCATION MAP											

C 965-04 In-place Density Report

Rev 1/16 C 965-04

**CIR DENSITY
DAILY REPORT**

PAGE 1 of 1

PROJECT _____	PR _____	DATE _____
CIR CONTRACTOR _____		DAY OF WEEK _____
PAVING CONTRACTOR _____		
WEATHER _____		GAUGE S.N. _____
CIR EMULSION _____		STD. COUNT M _____
CONTRACTOR'S EQUIPMENT _____		STD. COUNT D _____
TECHNICIAN NAME _____		TTQP QUAL. NUMBER _____

TEMPERATURE TARGET/ DAY _____ ACTUAL TEMPERATURE / DAY _____

TEST #	LOCATION	LIFT	SAMPLE #	THEORETICAL MAX. DENSITY	FIELD DENSITY (rotate 180°)	AVG. FIELD DENSITY (pcf)	PERCENT COMPACT.	TARGET
1								94%
2								94%
3								94%
4								94%
5								94%
6								94%
7								94%
8								94%
9								94%
10								94%

TIME BEGIN _____ TIME FINISH _____ HOURS _____ MILEAGE _____

REMARKS / LOCATION MAP _____

Appendix J

Time Charges

For Information Only

Designers: Include the following in Section 02221S of the Special Provisions

Time Charges

- A. Divide the time charges into four categories: Sampling Plan, Sampling, Pre-construction and Construction time.
- B. A maximum of 5 days Sampling Plan Charges are provided to the Contractor.
- C. A maximum of 5 days of Sampling Charges are provided to the Contractor.
- D. A maximum of 10 days Pre-construction Charges are provided to the Contractor.
- E. Sampling Plan Time charges begin at the Notice to Proceed (NTP) and continue until the contractor submits the Sampling Plan required in the specification. Penalties for time begin if the contractor submittal exceeds 5 working days after NTP.
- F. Time charges are suspended while the Department reviews the Sampling Plan.
- G. Sampling Time Charges start when the Sampling Plan is approved in writing by the Engineer and continue until the Contractor submits the required samples. Penalties for time begin if the contractor's sample submittal exceeds 5 working days after approval of the Sampling Plan.
- H. Time charges are suspended while the Department prepares the Mix Design.
- I. The Mix Design will be provided to the Contractor a minimum of 10 days before the pre-construction conference.
- J. Preconstruction time charges begin when the Department delivers the mix design to the Contractor. Penalties for time begin if the contractor fails to hold the pre-construction conference within 10 working days after the Department provides the mix design.
- K. Construction time charges begin the day of the pre-construction conference.